An Application of Micro-channel Plate Photomultiplier tube to Positron Emission Tomography

Outline

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1. Introduction

Time-of-flight PET

Use time-of-flight to localize positron decay position along 'Line-of-Response'.

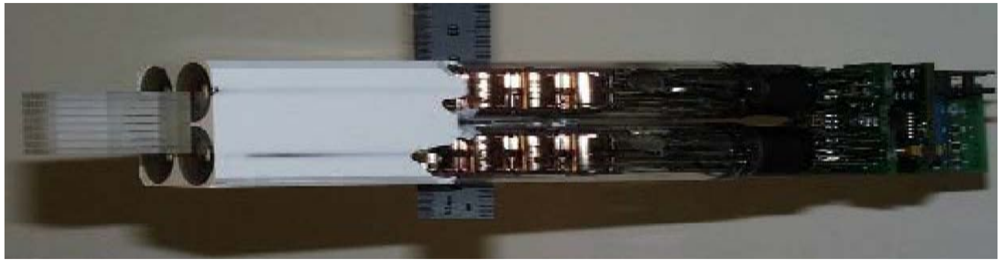
Advantages : improve image quality, reduce scan time, decrease injected dose, ..

Current commercial PET coincidence time resolution : ~570 ps (FWHM)

Target would be toward 200 ps, even 100 ps.

Current (TOF) PET technology

Scintillator + Photomultiplier tube + ADC/TDC(+CFD)



A block detector module
HRRT from CTI(Siemens)
(elongated to fit to slide)

We are exploring a TOF PET detector design using new technologies.

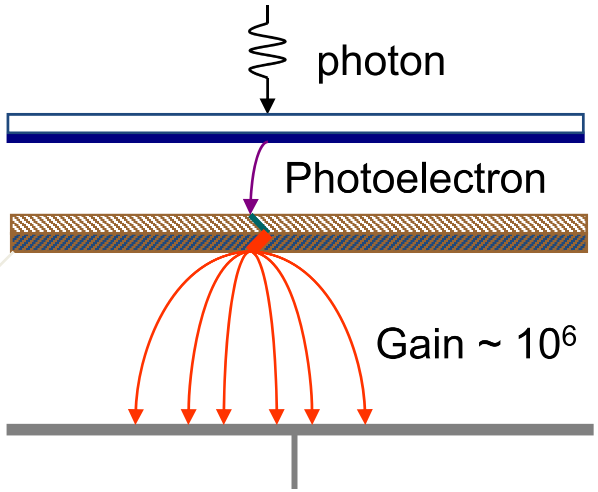
Micro-channel plate PMT; a fast photo-detector.

8"x8" flat panel MCP PMT development from LAPPD project.

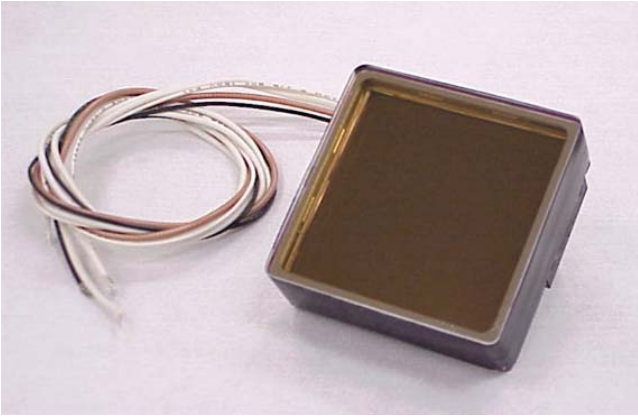
Transmission-line readout scheme to efficiently collect signal from 'large area'.

High speed waveform sampling based DAQ to ensure fast timing of MCP PMT.

Micro-channel Plate PMT



(from Paul Hink's slide at 2008 picosecond workshop)



Photonis XP85022 MCP-PMT
(2"x2", 14mm thickness)

- Faster time response
- Compact size
- Position sensitive
- Expensive cost

Large Area Picosecond Photo-Detector (LAPPD) project

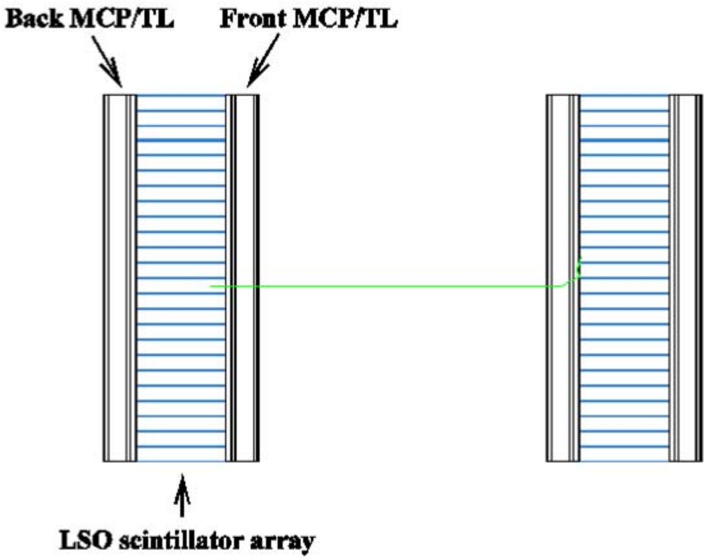
- Aiming to develop large area (8"x8") MCP-PMT
- Collaboration of Univ. of Chicago, Argonne, Fermilab,….
- Estimates a factor of ~10 cheaper than PMT per area.

When available, it can be applicable to PET instrument.

- Various PET design would be possible at reasonable cost.

For more info on LAPPD project, http://psec.uchicago.edu/
LAPPD related talks, #23, 60, 219, 438, 443, 457, 473, …

A PET detector design (Simulation)



- Two detector modules facing each other.
- One detector module consists of 24x24 array of LSO scintillator and 2 MCP/TL assemblies.
- LSO pixel dimension : 4x4x25mm^3.
  - Crystal pitch : 4.25mm
- MCP assembly dimension :
  102x102x9.15mm^3. (4”x4” of area)
  photocathode and TL structure are included.
- MCP/TLs are coupled to LSO at both front and back ends.
- Waveform sampling (20GSPS) for DAQ.

The design is suitable for TOF PET.

~11% FWHM of energy resolution at 511 KeV.

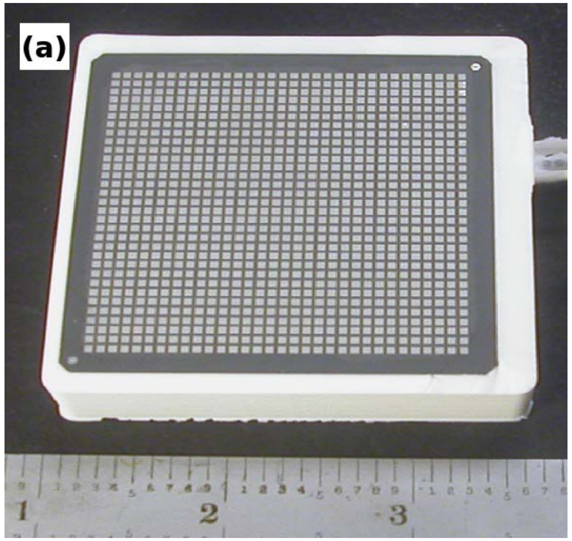
~320 ps FWHM coincidence time resolution.

~2.5 mm FWHM for position accuracy along a TL.

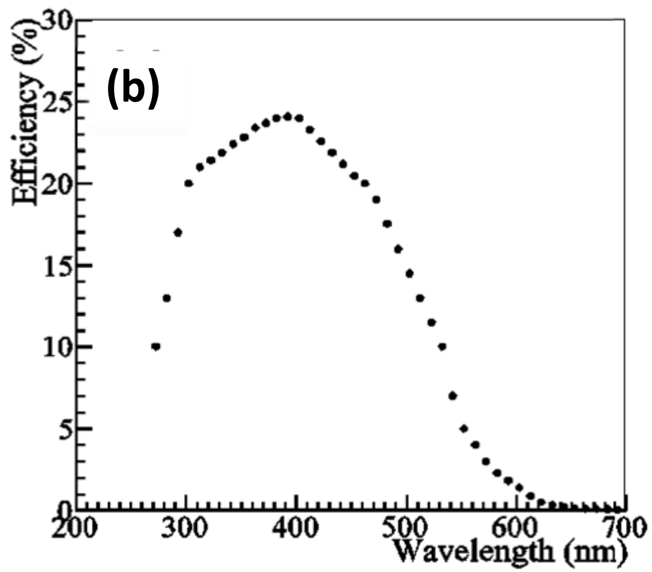
DOI Correlation in energy and time measured forward/back MCP/TL.

Cf. ‘A design of PET detector using MCP PMT…’, NIMA 622 (2010) p.628-636

2. Materials



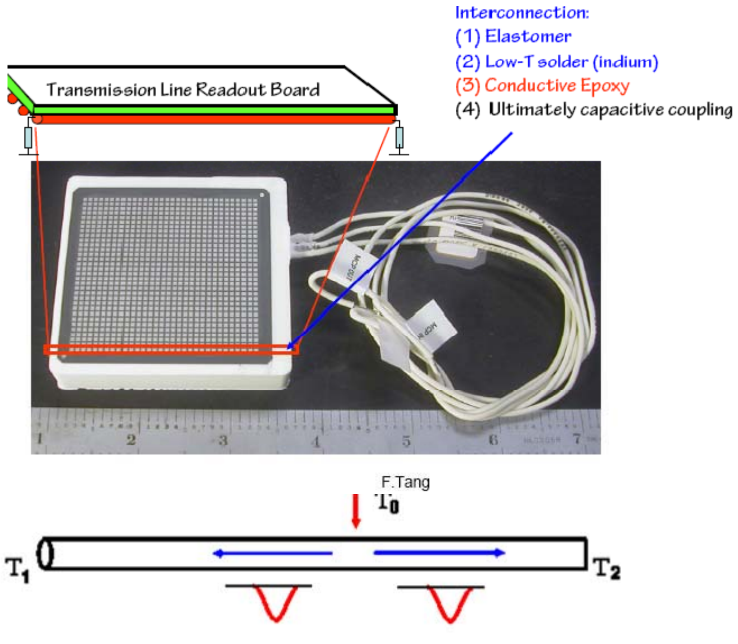
Photonis Planacon XP85022

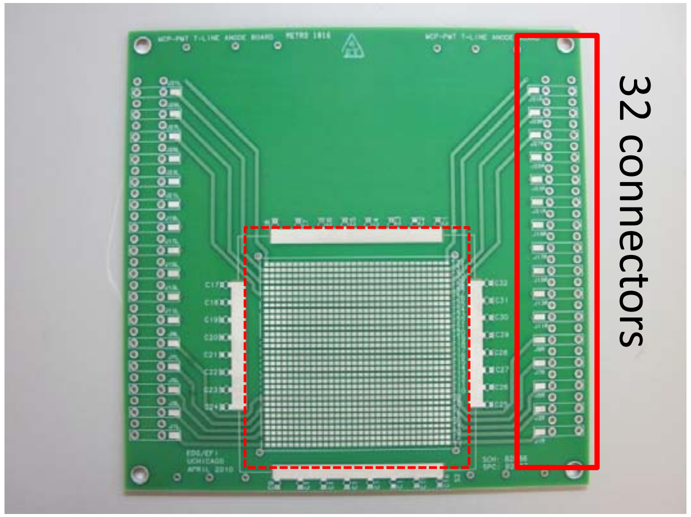


Quantum Efficiency

Window material	**Borosilicate, Corning 7056 or equivalent**
Photocathode	**Bialkali**
Multiplier structure	**MCP chevron (2), 25 µm pore, 40:1 L:D ratio**
Anode structure	**1024 (32×32 array), 1.1 / 1.6 mm (size /pitch)**
Active area	**53×53 mm (2”x2”)**
Open-area-ratio	**80%**

Transmission-line readout



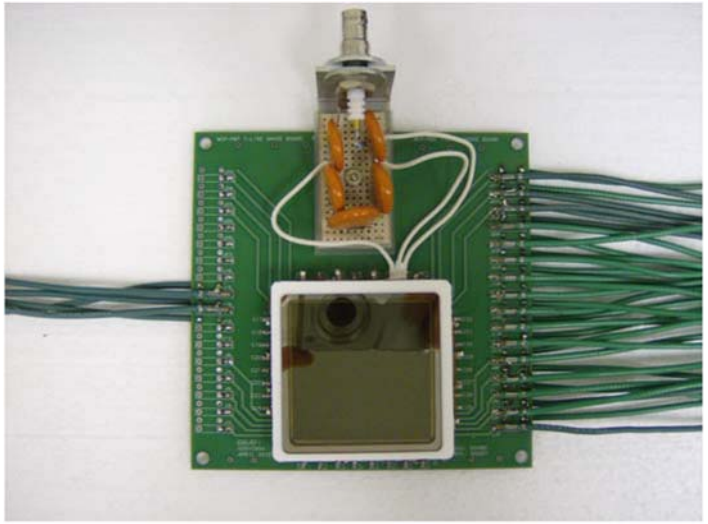


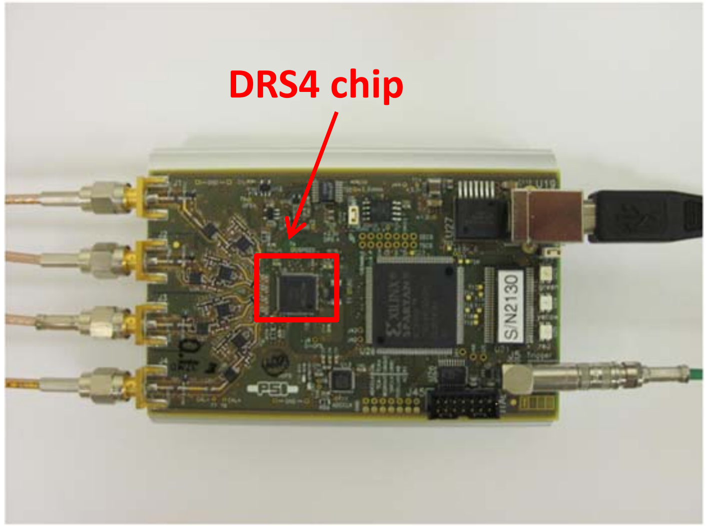
Transmission-line board

- Two correlated signals propagate to both ends.
  Timing : (T1+T2)/
  Position along TL : (T1-T2)
  Energy : Q1 + Q2
- An efficient way for large area readout.
  Scales to L, not L^2 as the area(L x L) increases.
- Require precise time decision.
  Waveform sampling.

- **<u>Prototype Transmissioin-Line board</u>**
- 32 micro-strip Z=50Ω lines
  Width = 1.1mm, Pitch = 1.6mm
- Matches anode structure of XP85022
- Solder the MCP anode on the board.
- need (32+32) readout channels.
  (32 + termination with 50Ω).

MCP/TL module + DRS4 sampling board





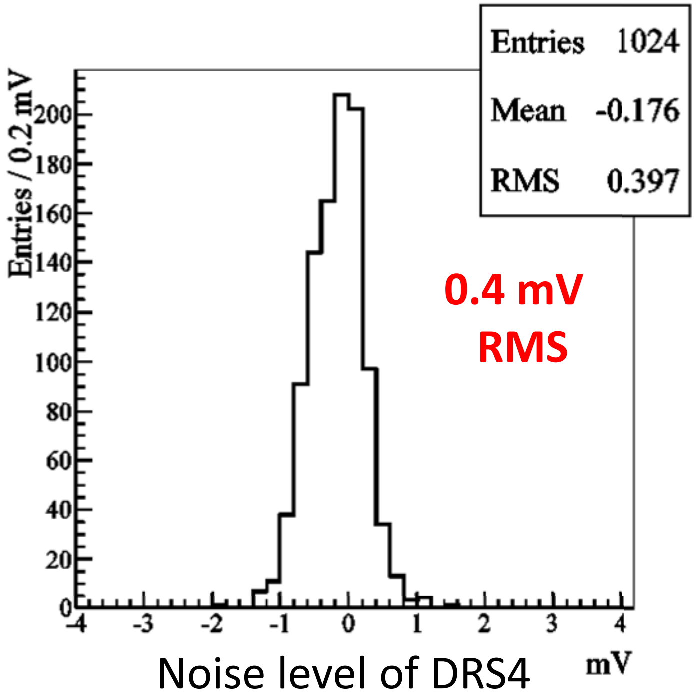
DRS4 evaluation board

Prototype MCP PMT/TL module.
3 units were built.
(32 + 4) channels are connected.

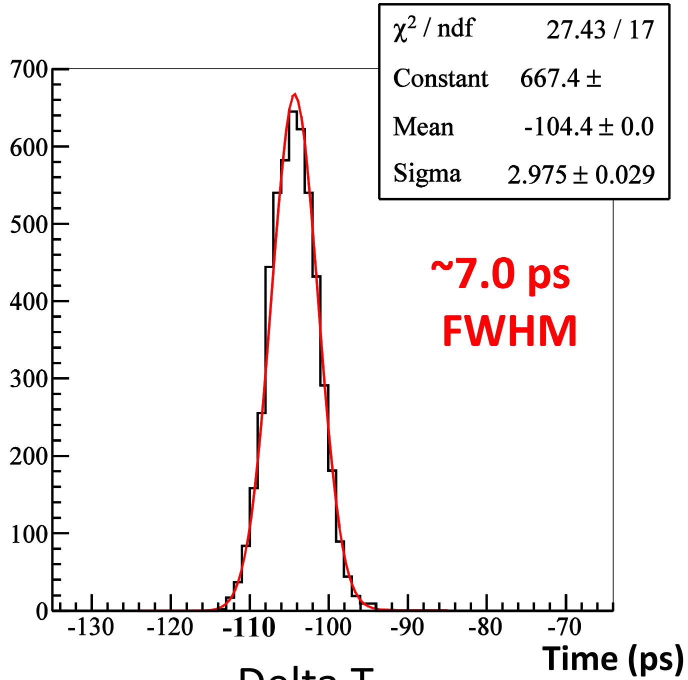
Domino Ring Sampler (DRS)
Switched Capacitor Array (SCA) technology.
Developed at PSI, Switzerland.
Sampling : 100 MSPS – 5GSPS
8+1 channels in one chip.
1024 sampling capacitors in one channel.
200 ns sampling range at 5GPS.
1 V of input dynamic range.
Need external ADC for digitization.
Analog bandwidth : 950MHz (-3dB)
Low power consumption : 10-40mW / channel

DRS4 evaluation board (available from PSI)
4 input channels.
USB 2.0 interface for DAQ.

DRS4 : noise level & timing



Noise level of DRS4



Delta T

Noise level of one channel is measured to be 0.4mV RMS running.

Consistent with DRS4 specification sheet.

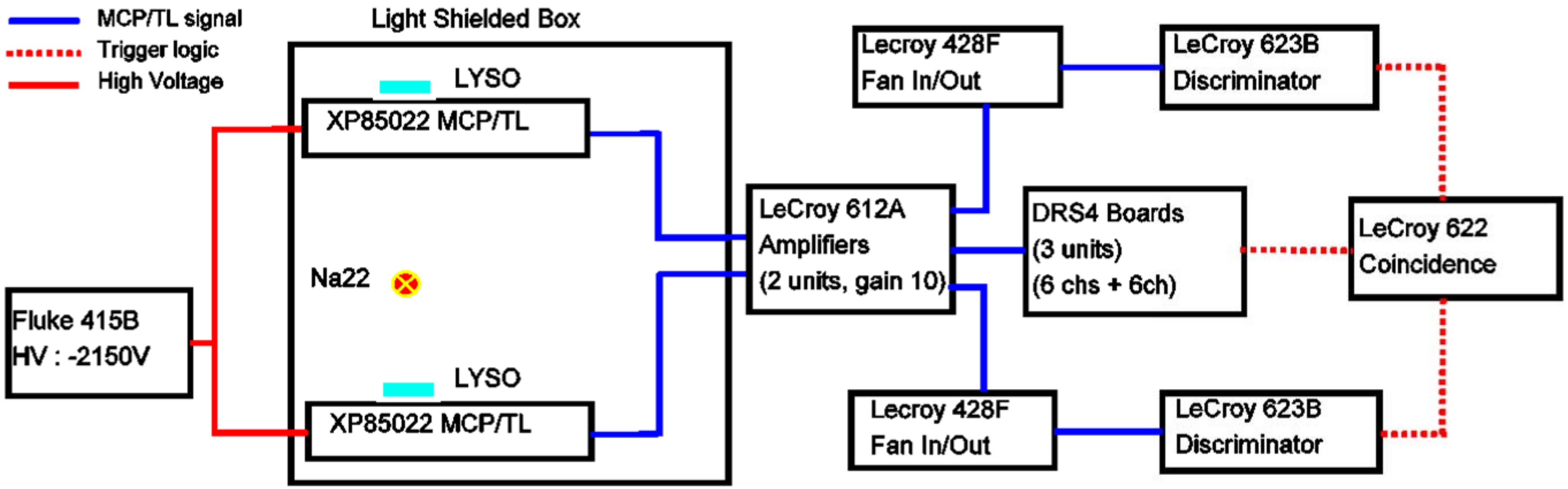
Time resolution of DRS4

Generate 2 ns width pulse with 600 mV amplitude (1 ns for rising & falling time).

Split the signal into two using T-connector, and feed them to two DRS4 channels.

Time resolution : ~7.0 ps (FWHM), (5.0 ps for one channel.)

3. Experimental tests

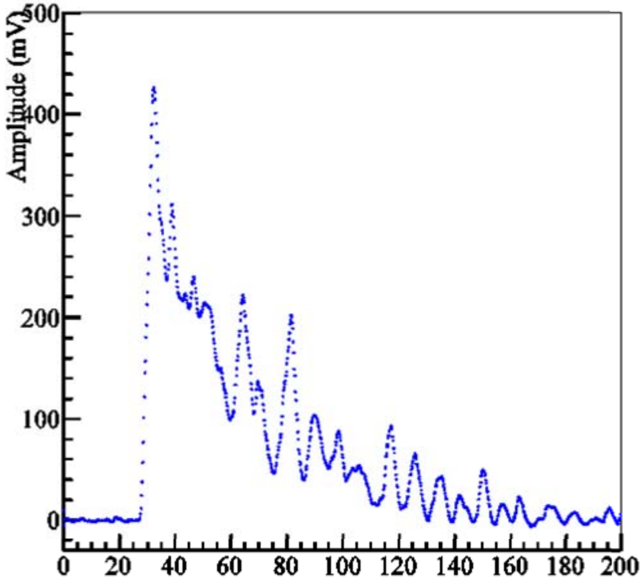


Block diagram of the test setup

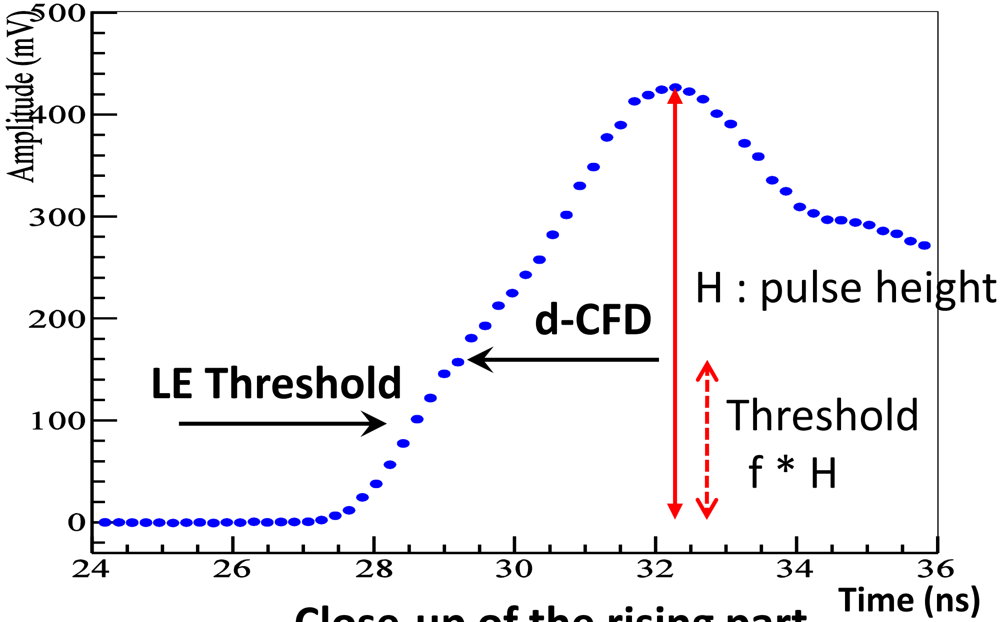
Two MCP/TL modules in coincidence mode. (5 cm distance between them)
3x3x20 mm^3 LYSO crystal coupled to each MCP with 3x20 mm^2 surface.
^{22}Na source is placed at the center.

HV: -2150V for XP85022 (gain ~10^6)
Use Lecroy 612 fast amplifier (gain 10) to enhance S/N.
3 units of DRS4 evaluation boards provide 12 (6+6) readout channels.
Sampling at **5GSPS** (200ns sampling range).

Recorded waveform sample



Waveform recorded from a TL



Close-up of the rising part

Event information

Energy : Area integration under pulse (150 ns range)

Timing : 1. Apply low pass filter

2. Interpolation (Cubic Spline)

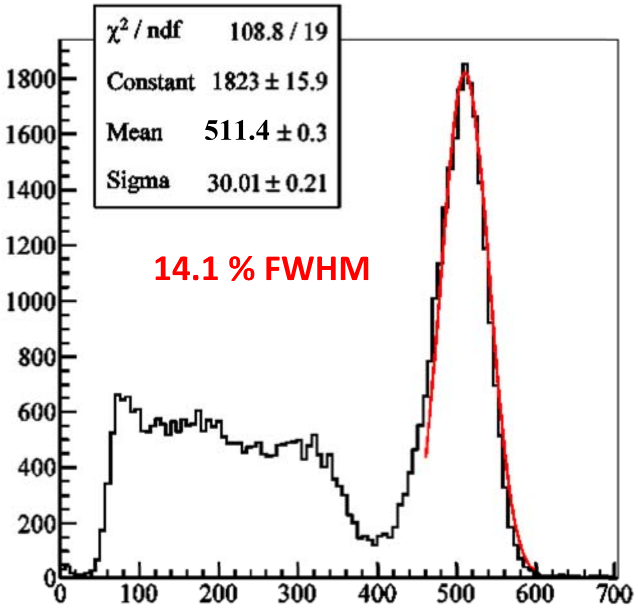
3. Time pick-up : Leading Edge (LE), d-CFD (digital Constant Fraction)

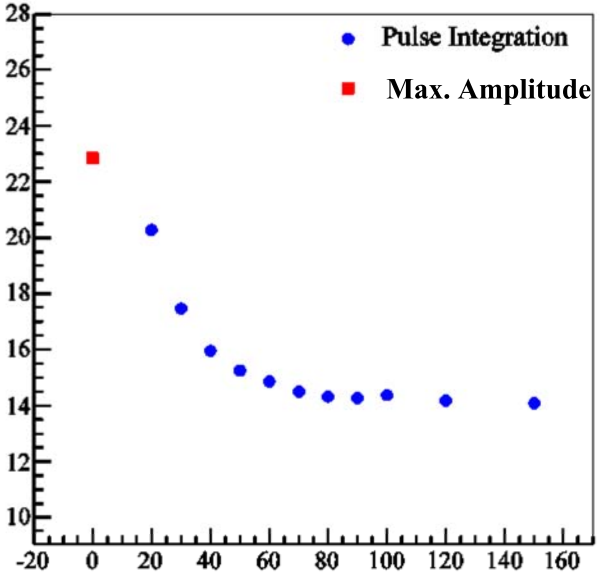
Multiple LE for time difference on a single TL.

Position : across Transmission-lines : energy weighted,

along a Transmission-line : from time difference

4. Results : Energy resolution at 511 KeV





<u>Energy sum of ten TLs</u>

one of MCP/TL was replaced by R9800 PMT in coincidence setup.

14.1 % FWHM energy resolution at 511 KeV

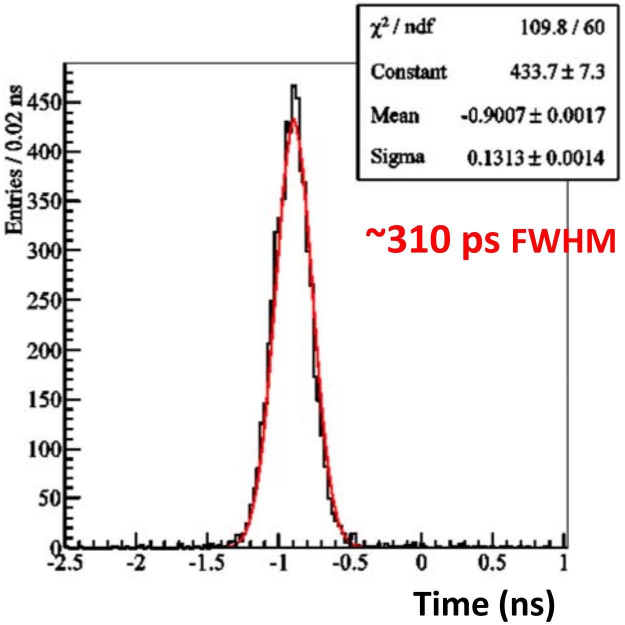
Integration time is 150 ns from the pulse start.

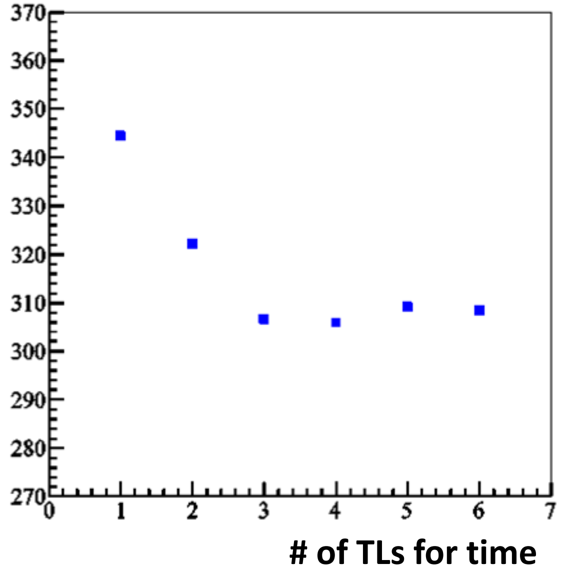
<u>Energy resolution as a function of integration time (20 – 150ns)</u>

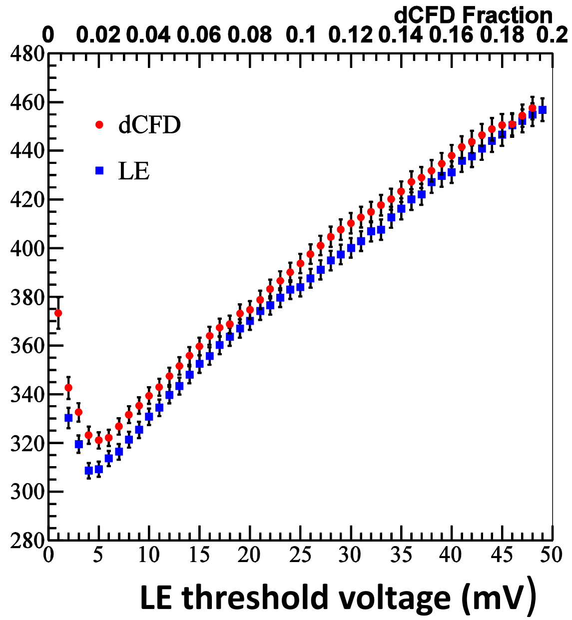
It doesn't improve with more than ~50 ns integration time.

Resolution at 0 ns is using the maximum amplitude information. (~2-5 ns)

Coincidence time resolution







Coincidence time is measured using 6 TL waveforms in each module.

(Left) **~310 ps FWHM coincidence time resolution** with 4mV threshold LE.

(Center) **Time resolution as a function of # of TLs for the time decision**

Use the average of TL times.

Start from the maximum energy TL.

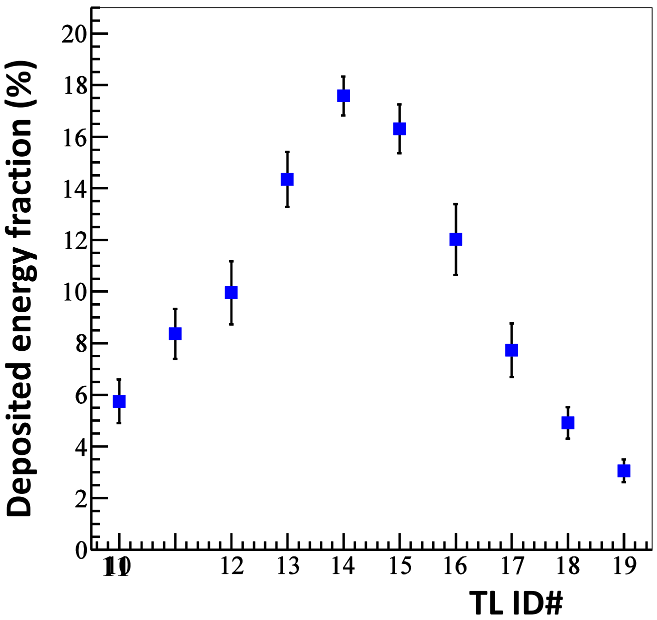
(Right) **Time resolution dependence on threshold** (2-50mV)

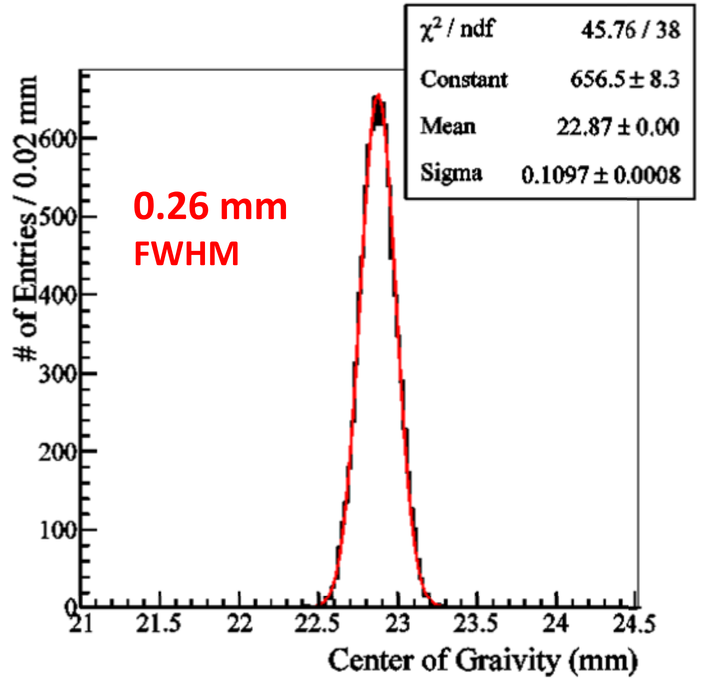
Best timing is obtained at 4-5 mV threshold.

-> First photo-electron arriving is important. (low noise electronics also)

d-CFD shows similar dependence (f : 0.004 – 0.2)

Position across TLs





(Left) Energy profile measured in 10 TLs

Normalized by the area (Energy sum)

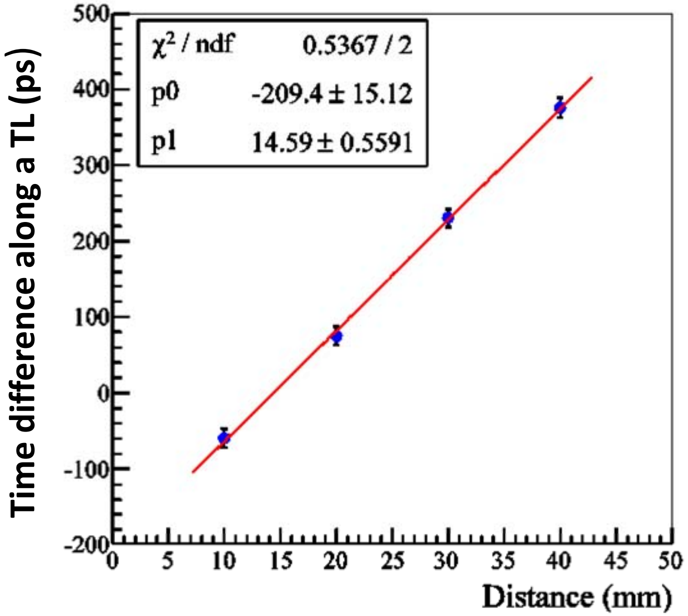
(Right) Position measured using 10 TLs

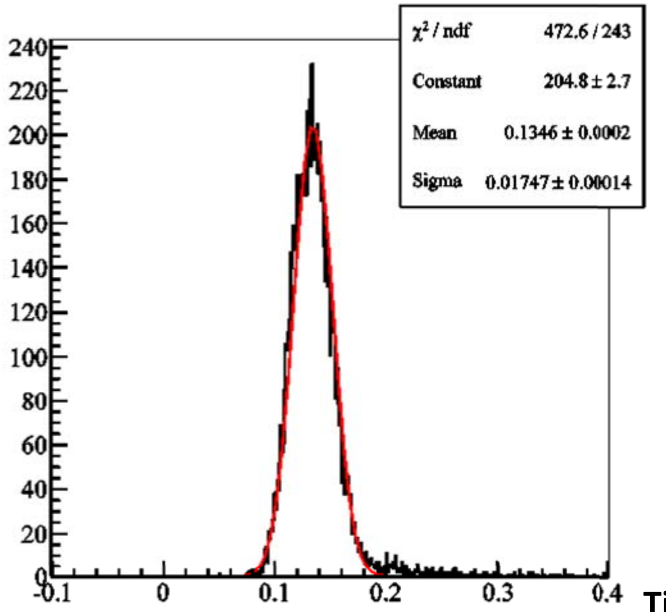
Determined by energy weighted TL position (1.6 mm pitch)

$$X = \sum x_i E_i / \sum E_i$$

Shows resolution **0.26 mm FWHM.**

Position along a TL





Differential time along a TL

(Left) Signal propagation speed

Measured the time difference at two ends of a TL:

LED light is moved by 10 mm step along a TL.

2*10 mm / 145 ps -> 0.48 *C* (speed of light) , consistent with PCB parameters.

(Right) Time difference along a TL from 511 KeV energy peak event

2.8 mm FWHM position accuracy inferred from 41 ps time resolution.

Use the maximum energy TL only.

Expect improved result by using multiple TLs.

5. Summary

- We are exploring a TOF PET detector design using large area(e.g., 8”x8”) flat panel MCP PMT, transmission-line readout scheme, and high speed waveform sampling abased data acquisition.
- Proto-type PET detector modules were built and tested, which use Photonis Planacon XP85022, transmission-line readout board and DRS4 waveform sampling board for a demonstration of the design concept.
- Preliminary experimental test results are promising for TOF PET.

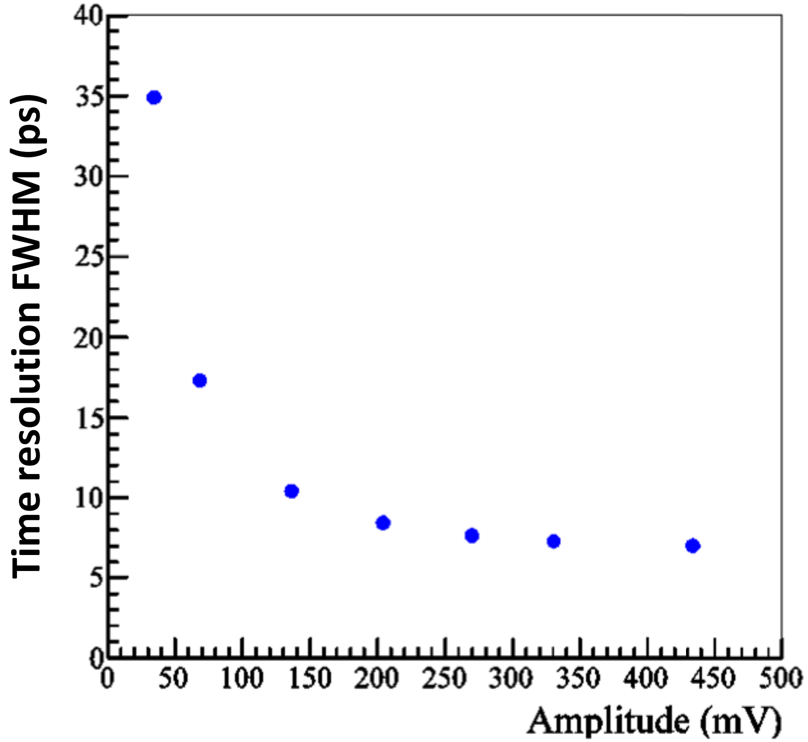
  Energy resolution : **14 % (FWHM)**

  Coincidence time resolution : **310 ps (FWHM)**

  Position resolution **: 0.26 mm across TLs**

  2.8 mm along a TL

Back-up : DRS4



Time resolution as a function of input amplitude to DRS4.